Incorporation of Condensation Heat Transfer in a Flow Network Code

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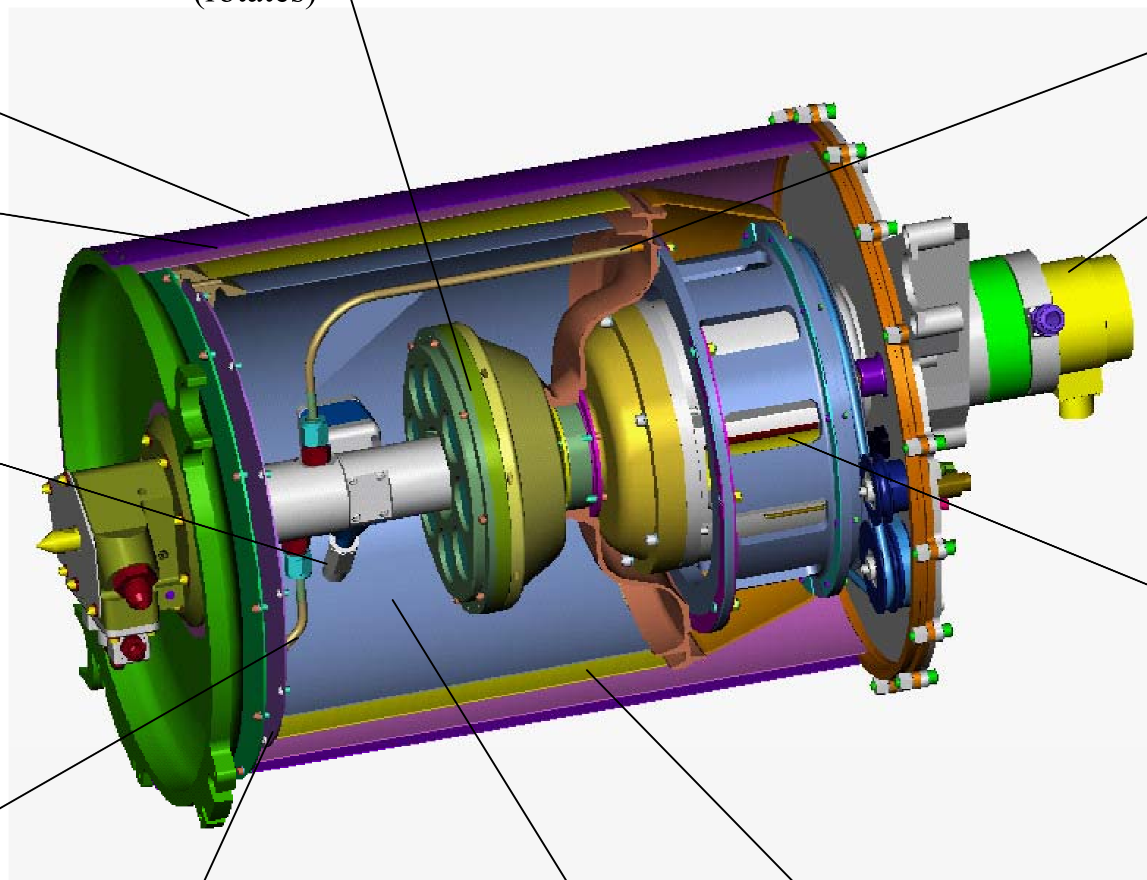
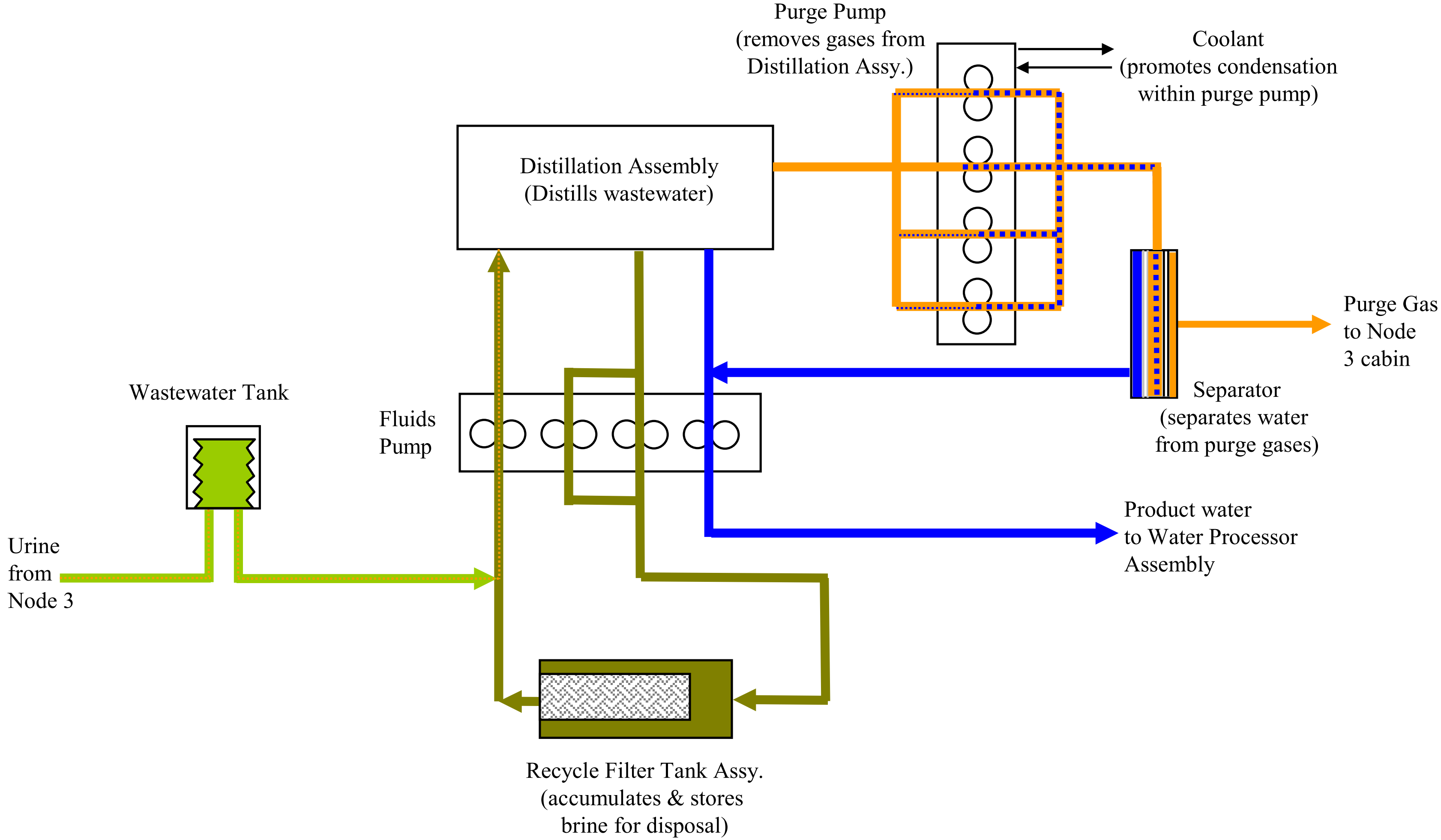
Introduction

- Pure water is distilled from waste water in International Space Station
- Distillation assembly consists of evaporator, compressor and condenser
- Vapor is periodically purged from the condenser to avoid vapor accumulation
- Purged vapor is condensed in a tube by coolant water prior to entering purge pump
- The paper presents a condensation model of purged vapor in a tube

UPA Distillation Assembly

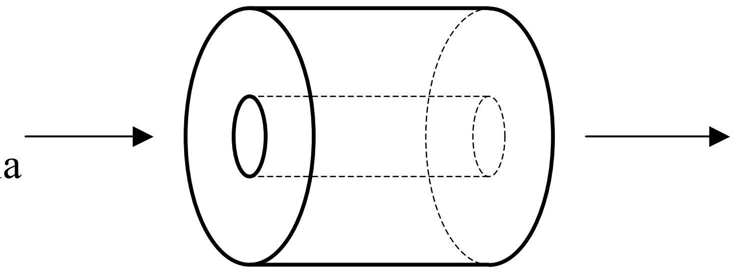


UPA Simplified Schematic



Problem Description

Superheated
Water Vapor
P_{inlet} = 0.95 psia
T_{inlet} = 101°F



Saturated
Water Vapor
P_{outlet} = 0.5 psia

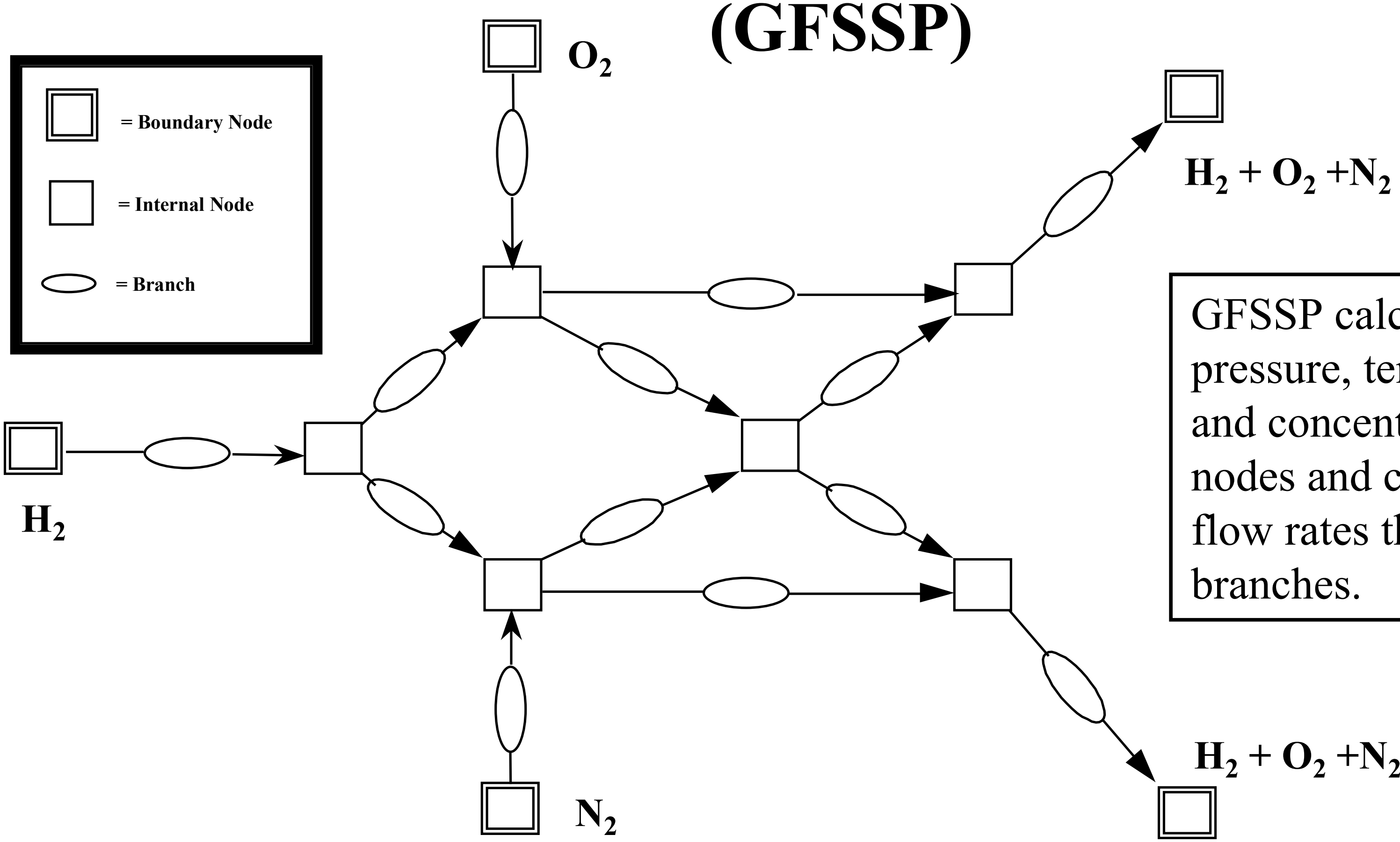
$T_{outer\ wall}$ = 65°F

Inner Tube Diameter = 0.125 inch
Outer Tube Diameter = 1 inch
Length = 4 inches
Material is Titanium

Calculate the Quality and Heat Transfer Properties of the Water as it Condenses in the Pipe

Model consists of 2 Boundary Nodes and 28 Internal Nodes and Models Conduction through the Tube Wall

Generalized Fluid System Simulation Program (GFSSP)

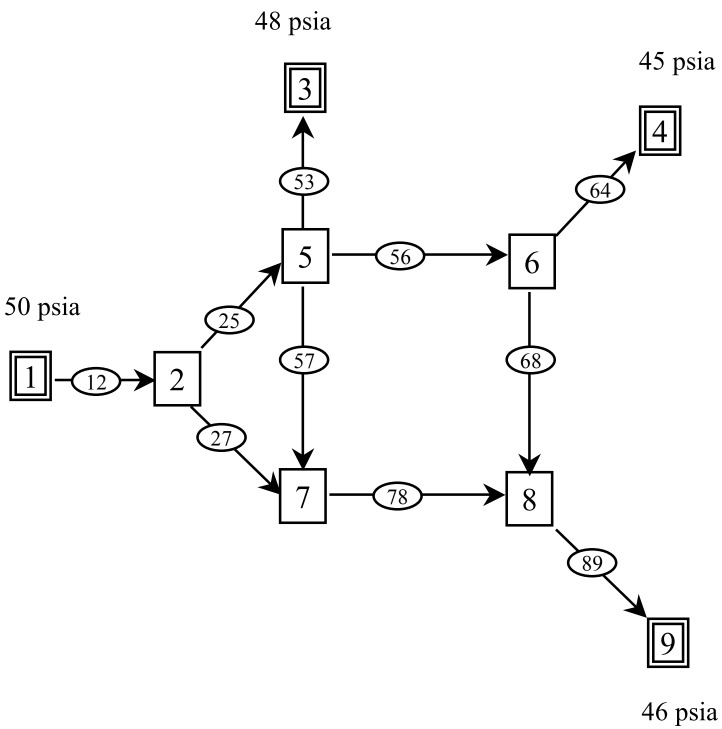


GFSSP calculates pressure, temperature, and concentrations at nodes and calculates flow rates through branches.

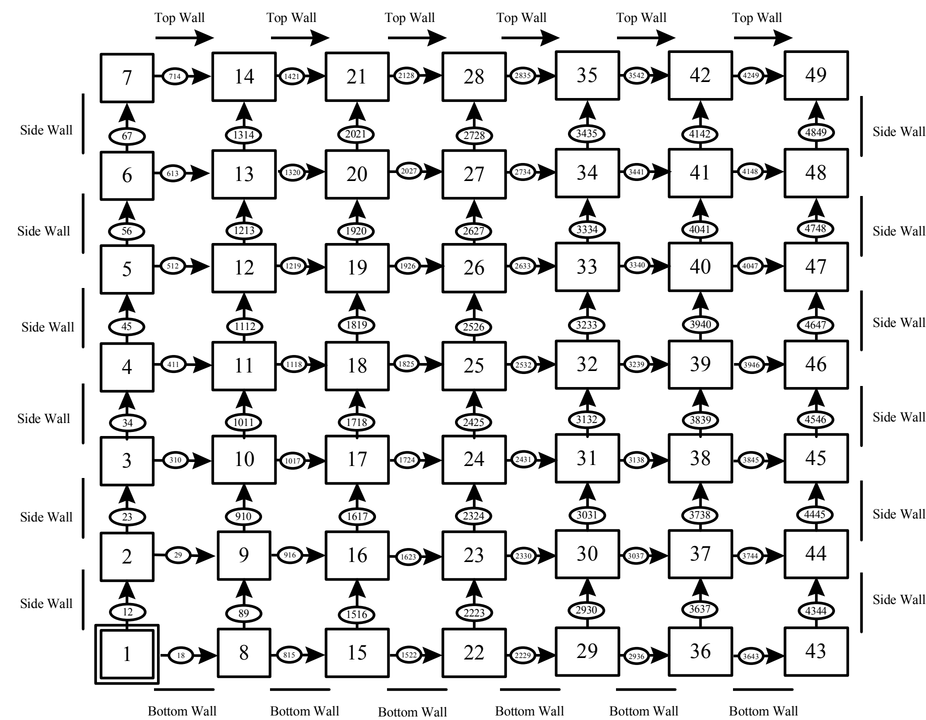
GFSSP
Finite Volume Method

- Finite Volume Method is based on conservation principle of Thermo-Fluid Dynamics
- In Classical Thermodynamics we analyze a single control volume
- In Finite Volume Method, flow domain is discretized into multiple control volumes and a <u>simultaneous</u> analysis is performed
- Finite Volume Method can be classified into two categories:
  - Navier-Stokes Solution (Commonly known as CFD)
  - Network Flow Solution (NFS)

GFSSP
Finite Volume Method



Network Flow Solution (NFS)



Navier-Stokes Solution (CFD)

GFSSP Process Flow Diagram

Preprocessor

- Command line preprocessor
- Visual preprocessor

Input Data File

Solver & Property Module

- Equation Generator
- Equation Solver
- Fluid Property Program

Output Data File

User Subroutines

New Physics

- Time dependent process
- non-linear boundary conditions
- External source term
- Customized output

Coupling of Thermodynamics & Fluid Dynamics

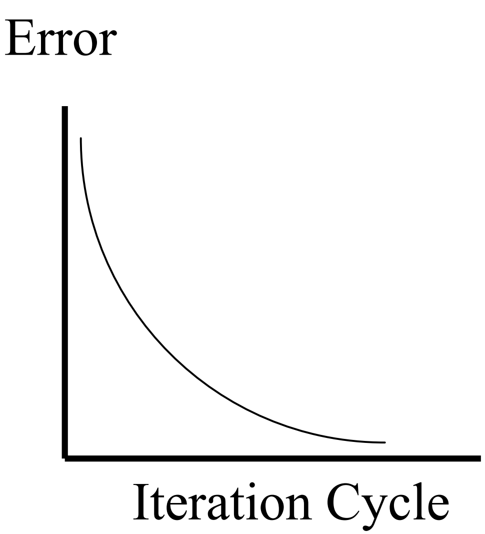
p – Pressure

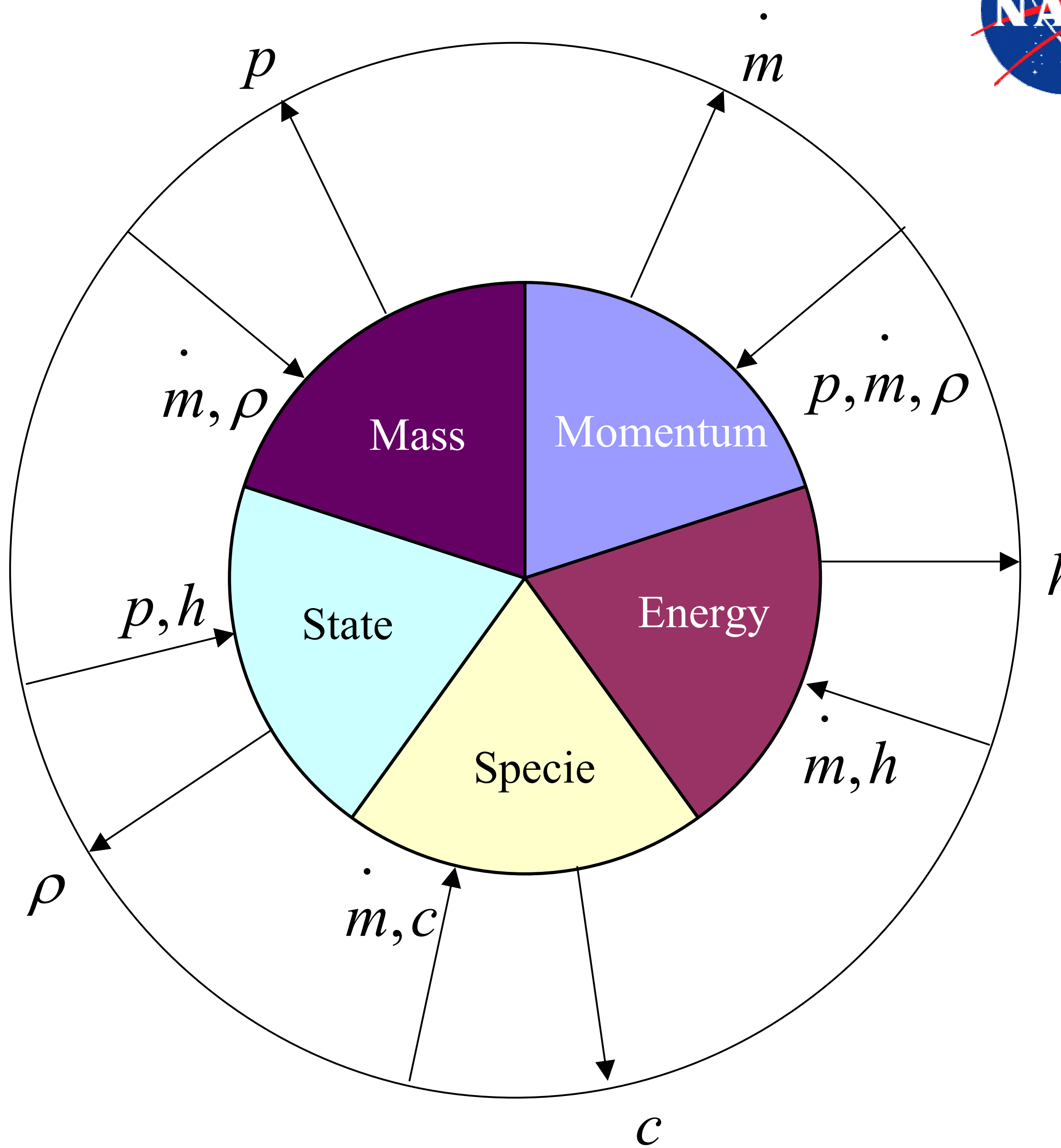
$\dot{m}$ - Flowrate

h - Enthalpy

c - Concentration

ρ - Density



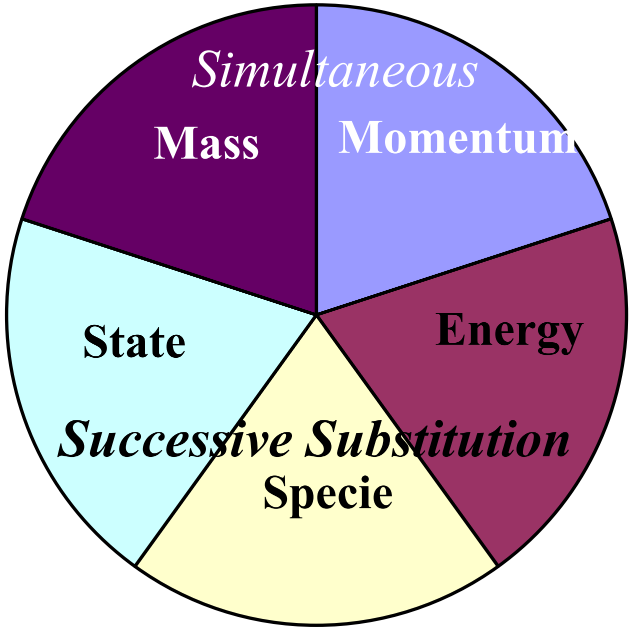


GFSSP Solution Scheme

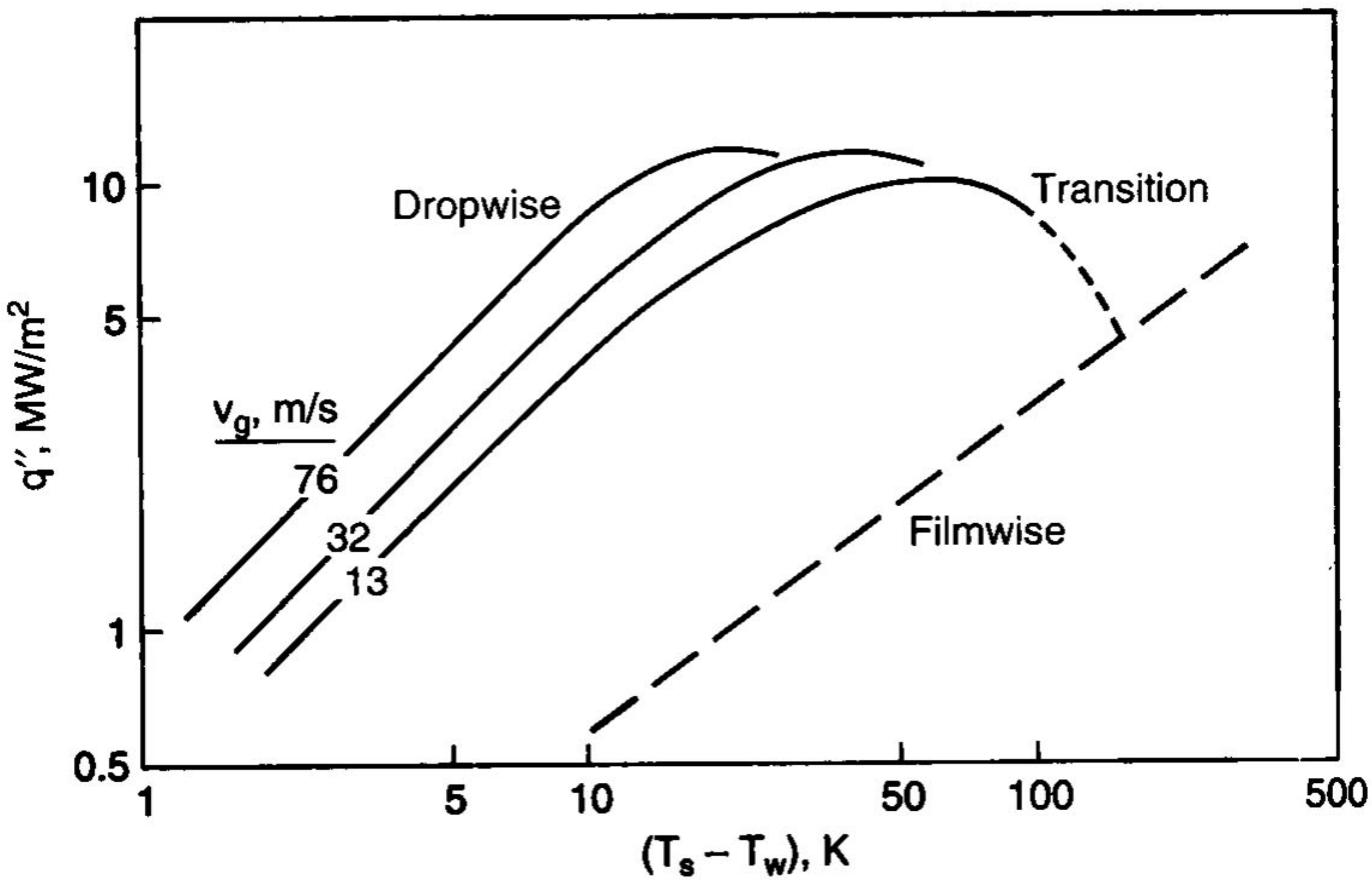
SASS : **S**imultaneous **A**djustment
with **S**uccessive **S**ubstitution

Approach : Solve simultaneously when equations are strongly coupled and non-linear

Advantage : Superior convergence characteristics with affordable computer memory



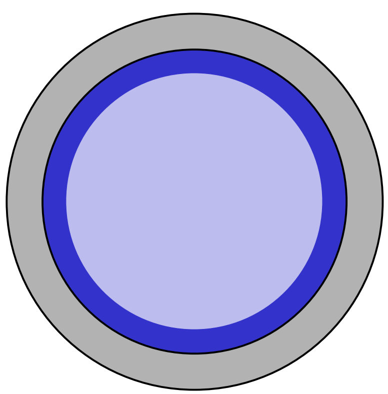
Condensation Heat Transfer



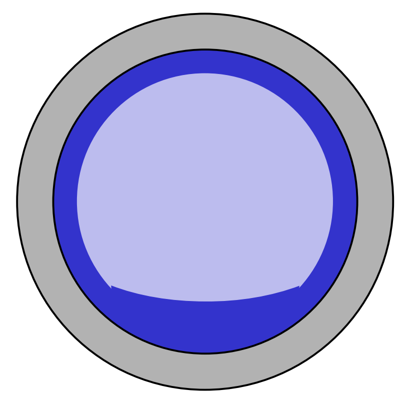
Heat transfer correlations

Akers, et al, 1959 – Annular Correlation
Boyko and Kruzhulin, 1967 – Annular Correlation
Chato, 1962 – Stratified Correlation
Soliman, et al, 1968 – Generalized Correlation

Chose Soliman correlation for its stability and generality



Annular Condensation



Stratified Condensation

Soliman Correlation for Heat Transfer Coefficient for Annular Flow Condensation

$$h = 0.036\,\mathrm{Pr}^{0.65}\,F_0^{0.5}\left[\frac{k_l \rho_l^{0.5}}{\mu_l}\right]$$

$$F_0 = F_f + F_m \pm F_a$$

$$F_f = 0.045\,\mathrm{Re}_T^{-0.2}\left[\frac{\pi^2 \rho_v D^4}{8W_T^2}\right]\left[x^{1.8} + 5.70\left(\frac{\mu_l}{\mu_v}\right)^{0.0523}(1-x)^{0.470}x^{1.33}\left(\frac{\rho_v}{\rho_l}\right)^{0.261} + 8.11\left(\frac{\mu_l}{\mu_v}\right)^{0.105}(1-x)^{0.940}x^{.860}\left(\frac{\rho_v}{\rho_l}\right)^{0.522}\right]$$

$$F_m = 0.5\left(D\frac{dx}{dz}\right)\left[\frac{\pi^2 \rho_v D^4}{8W_T^2}\right]\left[2(1-x)\left(\frac{\rho_v}{\rho_l}\right)^{2/3} + \left(\frac{1}{x} - 3 + 2x\right)\left(\frac{\rho_v}{\rho_l}\right)^{4/3} + (2x - 1 + \beta x)\left(\frac{\rho_v}{\rho_l}\right)^{1/3} + \left(2\beta - \frac{\beta}{x} - \beta x\right)\left(\frac{\rho_v}{\rho_l}\right)^{5/3} + 2(1 - x - \beta + \beta x)\left(\frac{\rho_v}{\rho_l}\right)\right]$$

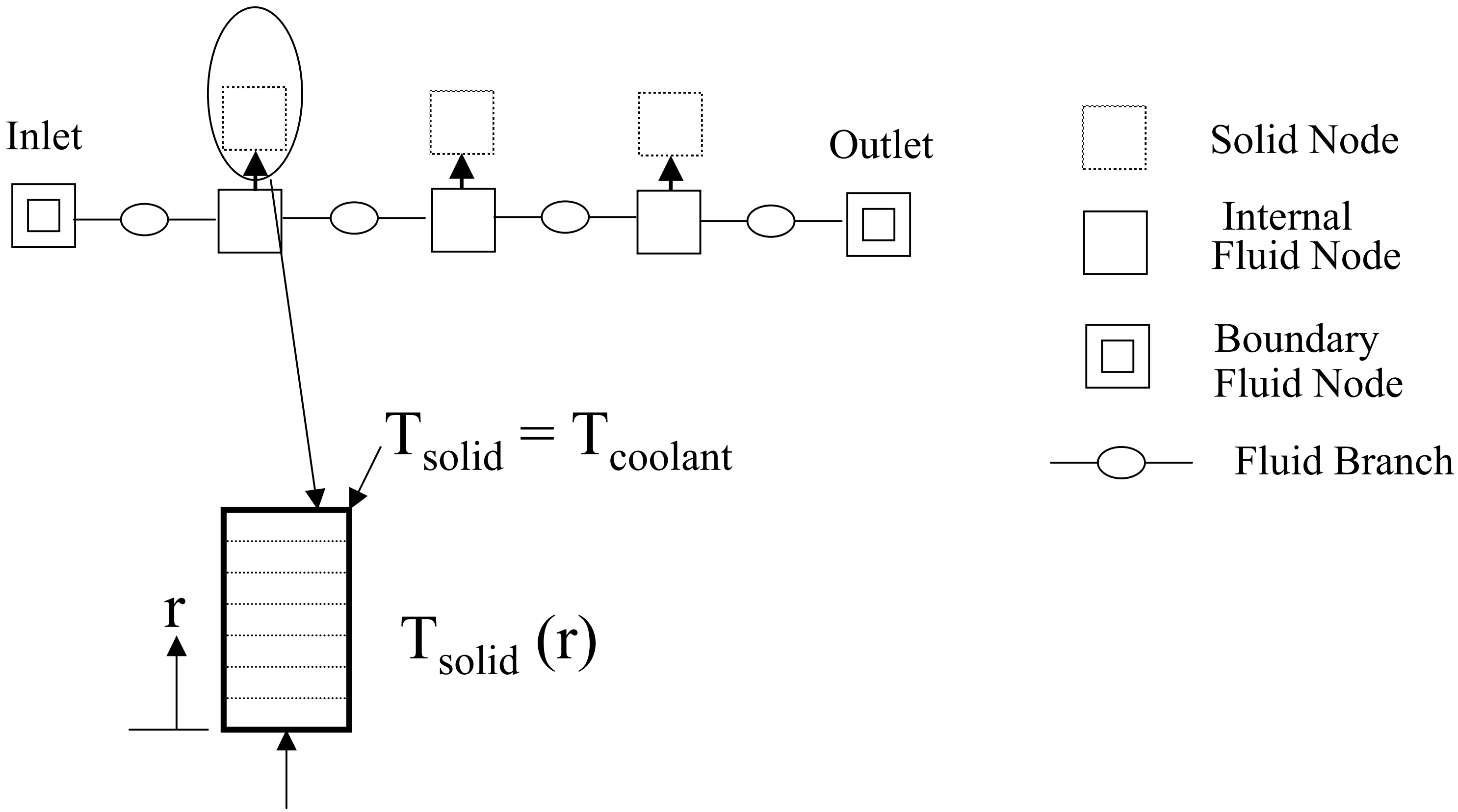
$$F_a = 0$$

F_f: Effect of two-phase friction

F_m: Effect of momentum changes in the flow

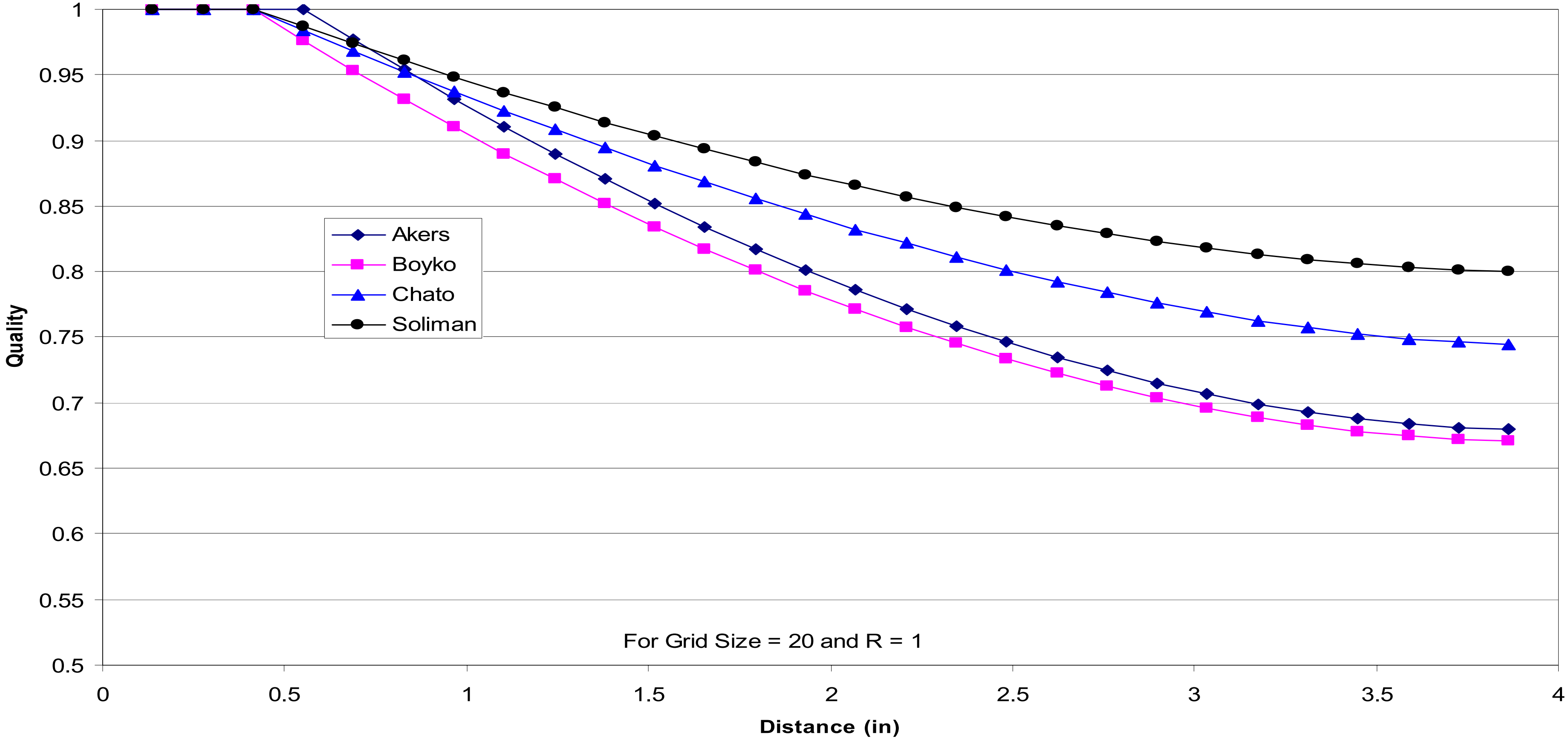
F_a: Effect of axial gravitational field on the wall shear stress

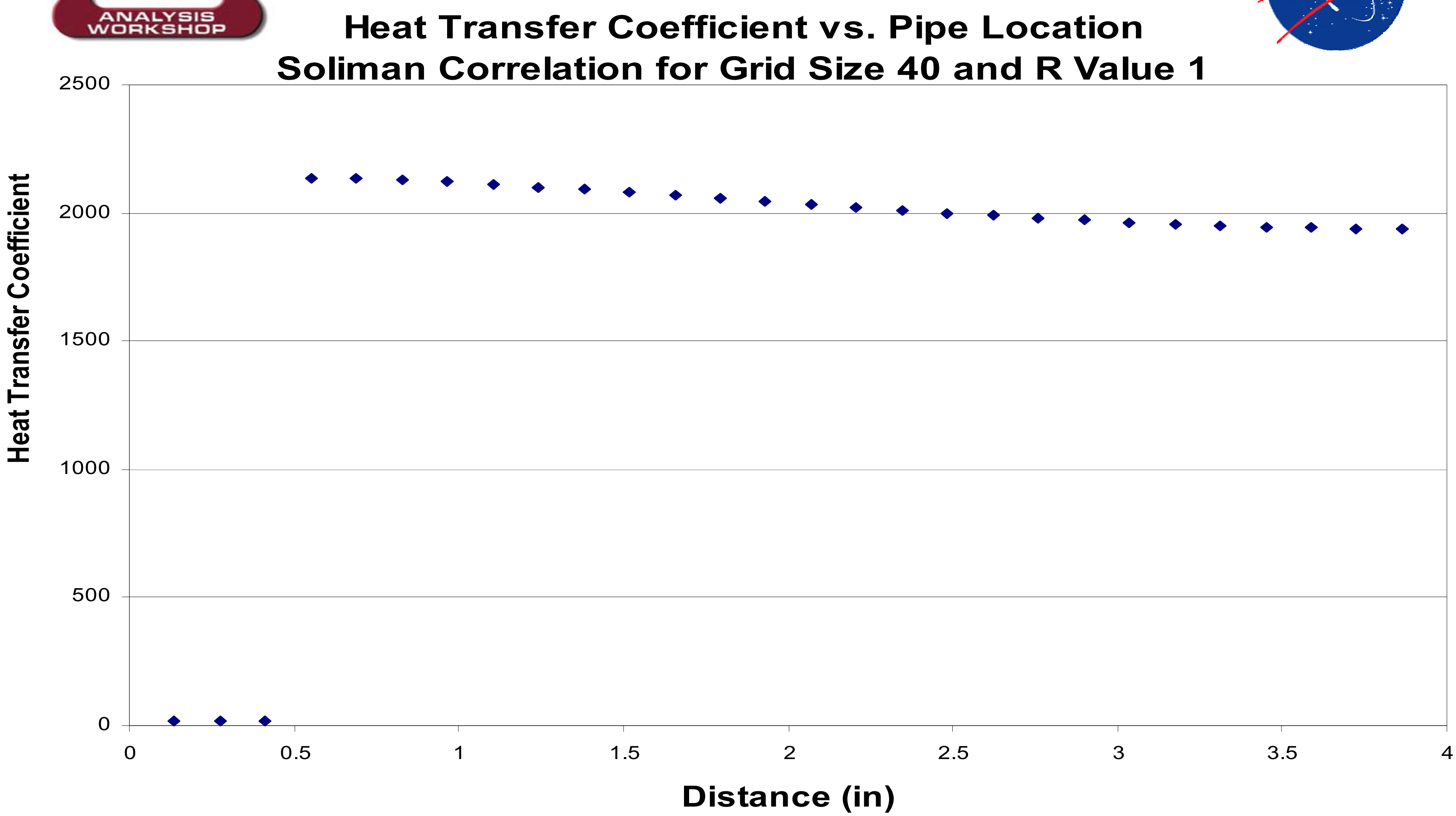
Solid-to-fluid heat transfer

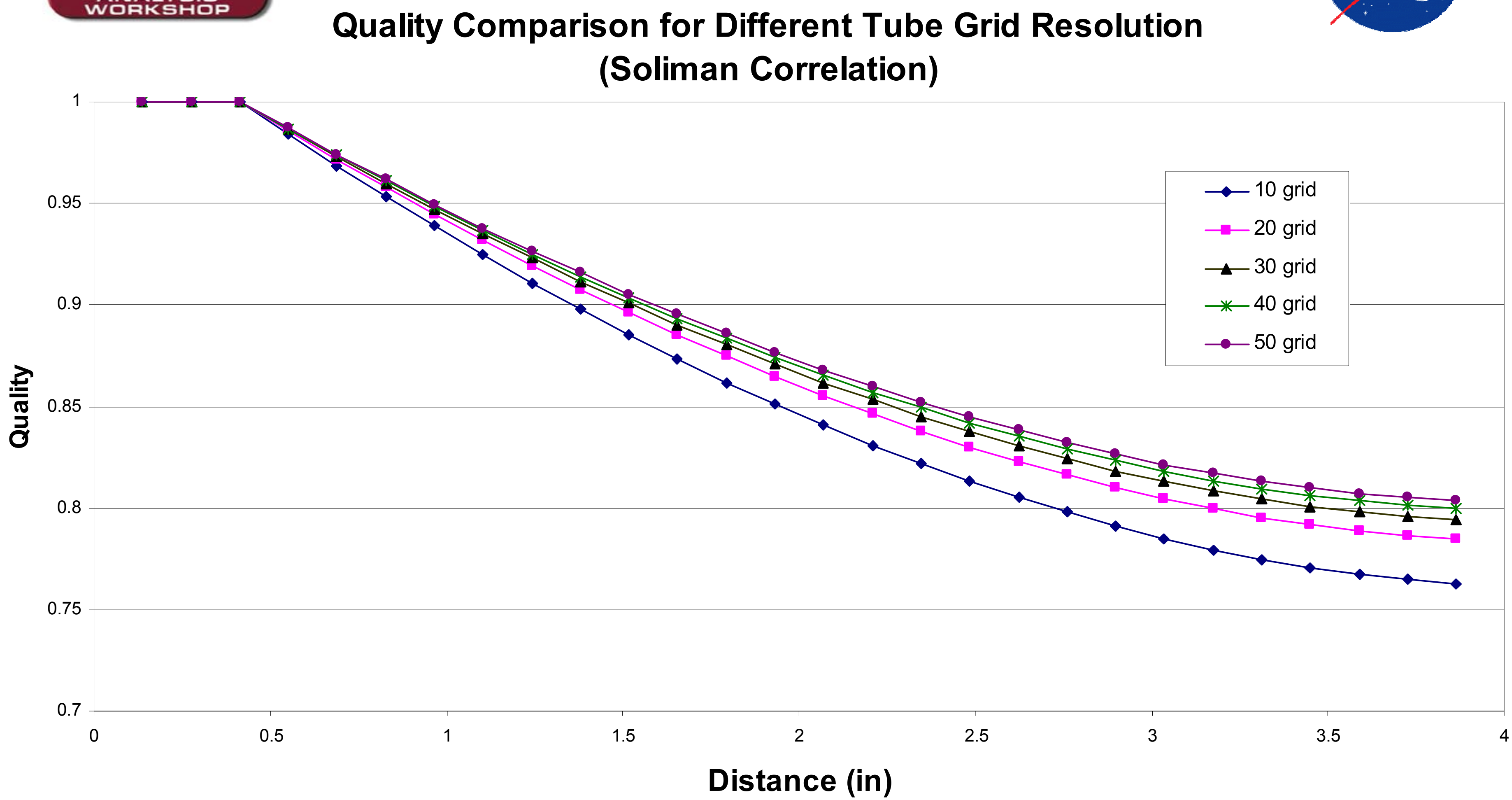


$$Q_{condensation} = h\ A\ (T_{fluid} - T_{solid})$$

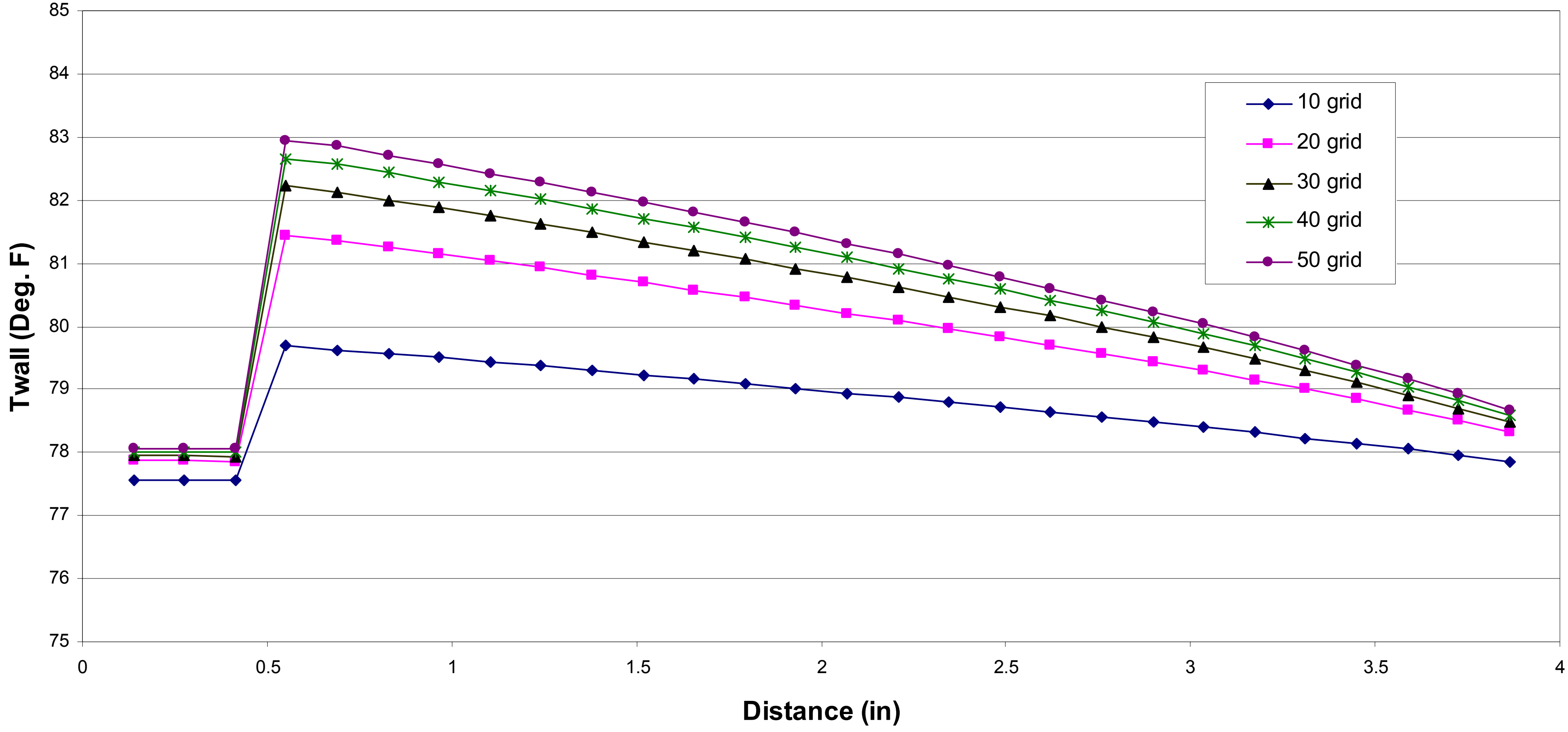
Plot of Quality vs. Pipe Location for Selected Heat Transfer Correlations




Heat Transfer Coefficient vs. Pipe Location
Soliman Correlation for Grid Size 40 and R Value 1
Heat Transfer Coefficient
2500
2000
1500
1000
500
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Distance (in)


Quality Comparison for Different Tube Grid Resolution
(Soliman Correlation)
Quality
Distance (in)
10 grid
20 grid
30 grid
40 grid
50 grid
1
0.95
0.9
0.85
0.8
0.75
0.7
0
0.5
1
1.5
2
2.5
3
3.5
4

Outer Wall Temperature Comparison for Different Tube Grid Resolution (Soliman Correlation)



Conclusions

- A condensation heat transfer model was successfully incorporated in a general purpose flow network code
- The numerical model considers solid-to-fluid heat transfer
- Soliman et al's correlation of condensation heat transfer is recommended due to its generality and stability

References & Acknowledgements

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